



Universiteit
Leiden
The Netherlands

Cardiac output measurement : evaluation of methods in ICU patients

Wilde, R.B.P. de

Citation

Wilde, R. B. P. de. (2009, June 11). *Cardiac output measurement : evaluation of methods in ICU patients*. Retrieved from <https://hdl.handle.net/1887/13834>

Version: Corrected Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/13834>

Note: To cite this publication please use the final published version (if applicable).

Chapter 2

Monitoring cardiac output using the femoral and radial arterial pressure waveform

R.B.P. de Wilde, R.B.G.E. Breukers, P.C.M. van den Berg and J.R.C. Jansen

*Department of Intensive Care, Leiden University Medical Center, Albinusdreef 2,
P.O.B. 9600, 2300 RC, Leiden, the Netherlands*

Published in:

Anaesthesia 2006 Aug; **61**(8):743-6

Letter to the editor and reply

Published in *Anaesthesia* 2007 Jan; **62**(1):90-1

Summary

This study was performed to determine the interchangeability of femoral artery pressure and radial artery pressure as input of the PiCCO system (Pulsion Medical Systems, Munich, Germany). We studied 15 intensive care patients after cardiac surgery. Five second averages of the cardiac output derive from the femoral artery pressure (CO_{fem}) were compared to 5 second averages derived from the radial artery pressure (CO_{rad}). The equality of the two PiCCO devices used in this study was confirmed.

One patient was excluded from our study because of problems in the pattern recognition of the arterial pressure signal. In the remaining fourteen patients, 14734 comparative cardiac output values were analysed. The mean sample time was 88 min, range [30-119 min]. Mean (SD) CO_{fem} was 6.24 (1.1) l.min⁻¹ and mean CO_{rad} was 6.23 (1.1) l.min⁻¹. The Bland-Altman analysis showed an excellent agreement with a bias of -0.01 l.min⁻¹, and limits of agreement from 0.60 to -0.62 l.min⁻¹. If changes in CO were larger than 0.5 l.min⁻¹, in 97% the direction of changes in CO_{fem} and CO_{rad} were equal. We conclude that femoral artery pressure and radial artery pressure are interchangeable as input of the PiCCO device allowing to change to the radial artery pressure line if the preferred femoral artery pressure line is no longer available for use.

Introduction

During cardiac surgery as well as during the first hours of ICU care, fluctuations in mean arterial pressure and cardiac index are the primary indicators for intervention [1]. When patients are hemodynamic unstable a continuous measurement of cardiac output is highly desirable. For this reason, different methods to monitor cardiac output continuously have found there way to the operating room (OR) and intensive care unit (ICU) [2-8]. Among the available pulse contour methods, the PiCCO system, with femoral artery pressure as input and calibrated by transpulmonary thermodilution, appears to have a clinical acceptable accuracy and tracking capability [9]. However, the femoral artery catheterization might become restrained in certain patients. In these patients, in whom the femoral arterial catheter is no longer available, the standard radial artery catheter seems a logical alternative, but this approach has not been validated yet.

Therefore the goal of the present study is to evaluate the interchangeability of femoral artery pressure and radial artery pressure as input of the pulse contour method of the PiCCO system in patients after cardiac surgery.

Patients and methods

Patients The study was approved by the hospital ethics committee and was conducted according to the principles stated in the Helsinki convention. Written informed consent was obtained the day before surgery. Fifteen patients (11 men and 4 women, mean age 73 years) scheduled to undergo elective cardiac surgery on cardiopulmonary bypass (11 patients with CAGB and 4 patients with mitral valve annuloplasty) were included in the study. Patients with significant valvular regurgitation and/or atrial fibrillation, aneurismal deformities to the aorta or symptomatic peripheral vascular disease were excluded. Patients were pre-medicated with sublingual lorazepam (0.05mg/kg). Radial arterial blood pressure was monitored via a 20 Gauge, 3.8 cm long radial catheter inserted by Seldinger technique and connected to a pressure

transducer (PX600F, Edwards Lifesciences). Central venous pressure was measured with a MultiCath 3 venous catheter (Vigon GmbH & Co, Aachen, Germany), connected to a pressure transducer (PX600F, Edwards Lifesciences). Anaesthesia during surgery was performed according to institutional standards.

After transfer of the patients to the ICU, a second arterial pressure line was inserted with a Seldinger technique into the right femoral artery (4F, 16cm long thermistor-tipped arterial catheter PV2014L16; Pulsion Medical Systems, Munich, Germany) and connected to a cardiac output monitor (PiCCO, Pulsion). Pulse contour cardiac output was calibrated with 3 transpulmonary thermodilution measurements. For each thermodilution measurement, 20ml cold (3-8°C) saline was injected, via the central venous catheter. The results and calculated average of the 3 cardiac output measurements were documented.

All patients were mechanically ventilated with an oxygen level of 40%, a respiratory frequency of 12-14 min⁻¹, and positive end expiratory pressure of 5 cmH₂O. Tidal volume (6-8 ml.kg⁻¹) was adapted to maintain the arterial PCO₂ between 40 and 45 mmHg. A hemodynamic stable status was achieved using fluids and catecholamines. The observation period started after introduction of the femoral artery catheter and stopped at the onset of weaning. During the observation period, up to 6 hours, the radial artery pressure, femoral artery pressure and central venous pressure were continuously stored on computer disk. The sample frequency was 100Hz and the resolution 0.2 mmHg. It should be noted that during this recording sessions great care was taken to flush, check, and if necessary, re-zero the pressure transducers when necessary. Every patient experienced full recovery from anaesthesia within 8 hours and was discharged from ICU the next, first post-operative day.

Data analysis

Applying the same femoral blood pressure to both devices for 103 minutes, the equality of the two PiCCO monitoring devices was tested. The two devices were calibrated using the same calibration factor. The pulse contour output data of the PiCCO devices was collected with a computer program (PiCCOWin, Pulsion, Munich, Germany), with 5-second averages to allow statistical analysis.

Next, from each patient, the radial and femoral arterial pressure was played back from the computer disk (for at least a 1-hour period) to the two PiCCO monitoring devices. PiCCO1 was used for cardiac output from the femoral pressure (CO_{fem}) and PiCCO2 was used for cardiac output calculations of the simultaneously played back radial arterial pressure (CO_{rad}). At start the cardiac output values were set equal to the mean of the three values documented at the bedside. For both CO_{fem} and CO_{rad} the same calibration factor was used. The pulse contour output data of the PiCCO devices were collected with a computer program (PiCCOWin), and the averaged data were stored on a computer disk every five seconds.

Statistics

The mean statistical tool is the Bland-Altman analysis with differences in data pairs plotted against their mean [10]. The agreement between CO_{fem} and CO_{rad} was computed as bias [mean (SD)], with limits of agreement computers as bias ± 2SD. Of each patient, changes in CO_{fem} and changes in CO_{rad} were calculated by subtracting the measured cardiac output value from the mean cardiac output value of the patient. The agreement of changes in cardiac output were computed using a cross tabulation. Data are given as mean (SD). Statistical significance was considered present for $p < 0.05$.

Results

The equality of the two devices was tested with the same femoral artery pressure as input for both devices. We obtained two sets of 1243 data points, each data point being 5-second average of the pulse contour cardiac output. These two sets were marked with PiCCO1 and PiCCO2. Using these sets, no difference was found between the two monitoring devices (bias 0.03 l.min^{-1} , 95% CI -0.0015 to 0.0067 , $p = 0.215$). The upper and lower limits of agreement were 0.151 and $-0.145 \text{ l.min}^{-1}$, confirming an excellent agreement between both cardiac output devices.

In fifteen patients, radial and femoral artery blood pressure was recorded. An illustration of an individual patient is presented in figure 2a.1.

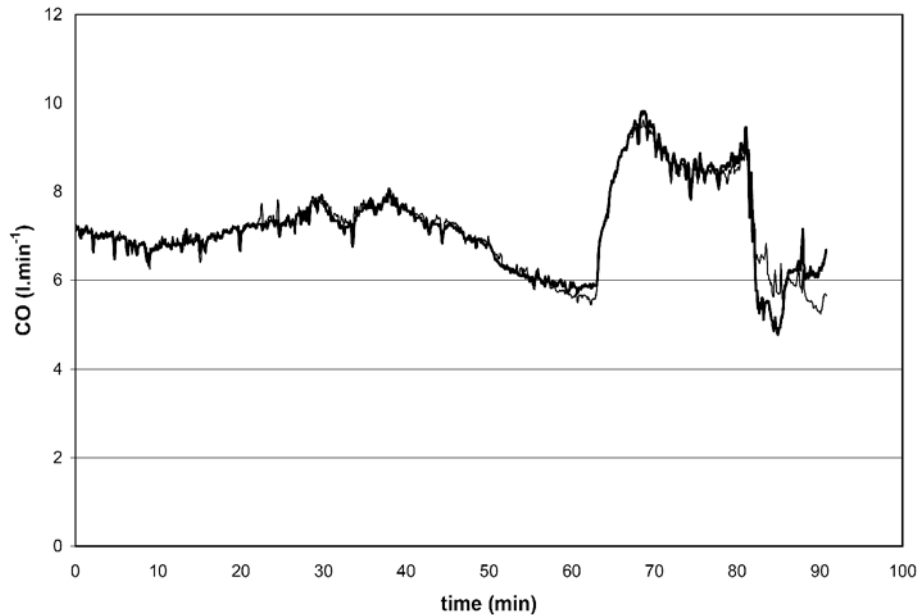


Figure 2a.1 Data of an individual patient. Thin line pulse contour cardiac output (CO) from the femoral artery pressure and solid line CO from the radial artery pressure.

One patient was excluded because of problems with the pattern recognition of the pressure signal, visualized on the screen of the PiCCO devices. From the remaining fourteen patients we analyzed a total of 1053 recording minutes (per patient mean 88 min, range [30-119 min]) resulting in 14734-paired values of CO_{rad} and CO_{fem}. The mean cardiac output measured with the femoral blood pressure was 6.24 , SD $(1.1) \text{ l.min}^{-1}$ and with the radial arterial pressure 6.23 , SD $(1.1) \text{ l.min}^{-1}$. This irrelevant small difference was, however, statistically different from zero ($p = 0.05$).

The Bland-Altman analysis (Fig. 2a.2) showed in excellent agreement between CO_{fem} and CO_{rad}. The irrelevant small bias of $-0.007 \text{ l.min}^{-1}$ was significant different from zero (95% CI = -0.012 to -0.002 , $p = 0.05$) with upper and lower limits of agreement of 0.60 and -0.62 l.min^{-1} , respectively.

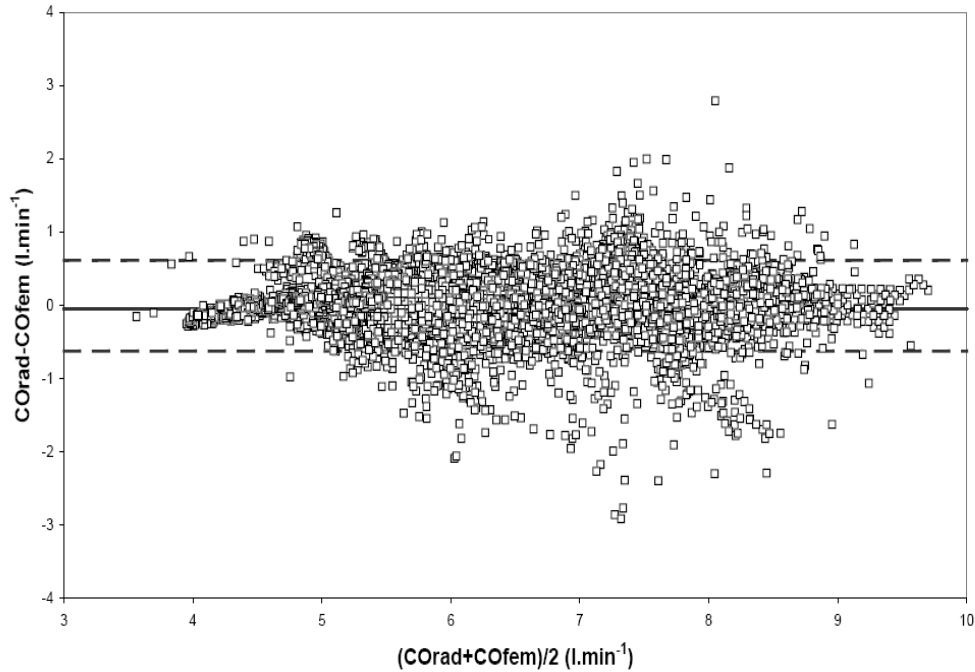


Figure 2a.2 Bland-Altman plot with pulse contour cardiac output from the femoral artery pressure (CO_{fem}) and from the radial artery pressure (CO_{rad}). The solid line represents the bias and the dashed lines the limits of agreement.

Trending capability of the methods is indicated by plotting the relationship of changes of CO_{fem} versus changes of CO_{rad}, figure 2a.3. It is noticeable that in this relationship ideally all data point should be placed in the upper-right and the lower-left quadrant. The agreement of positive and of negative changes of CO_{fem} and CO_{rad} was calculated by a cross tabulation. We found 84.8% of the changes in agreement with each other. When accepting a change in cardiac output smaller than $\pm 0.5 \text{ l.min}^{-1}$, as not clinically relevant, then 97.3 % of the changes are in agreement of each other.

Discussion

Our study demonstrated that the radial artery pressure is interchangeable with the femoral artery pressure as input of the PiCCO device. This result allows continuing cardiac output monitoring in case of a problem with the femoral artery pressure line by switching over to the more commonly used radial artery pressure line.

The accuracy of pulse contour cardiac output from the femoral artery pressure calibrated by the transpulmonary arterial thermodilution technique using the PiCCO system has been studied in a number of different patient populations with clinically accepted results [9]. However, in cardiac surgical patients, femoral artery catheterization is often avoided to keep unrestricted access to the groin for cardiopulmonary bypass cannulation or placement of an intra-aortic balloon pump when necessary [12]. Therefore, L'E Orme et al. [11] and Wouters et al. [12] investigated the feasibility of the brachial arterial approach to compute cardiac output.

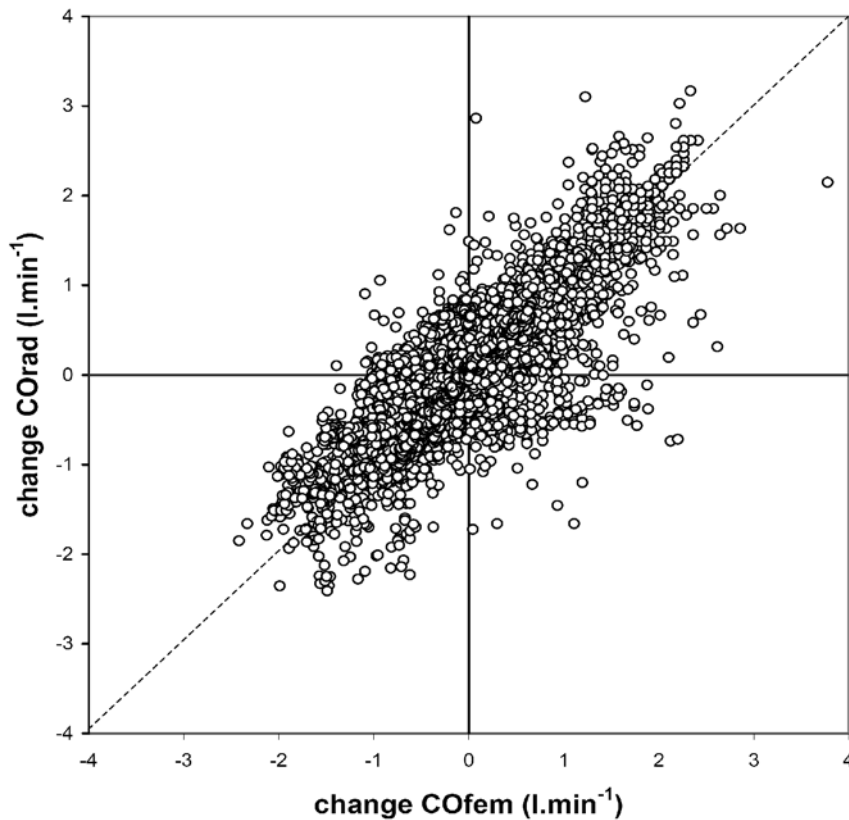


Figure 2a.3 Relationship between changes in femoral artery pulse contour cardiac output (change CO_{fem}) and changes in pulse contour radial artery cardiac output (change CO_{rad}). Ideally all data points should be in the upper right and in the lower left quadrant. The line of identical change is indicated, dashed line.

In both studies the transpulmonary thermodilution values found via the brachial artery agreed with the results obtained from the pulmonary artery catheter, bias 0.38, SD (0.77) l.min⁻¹ and 0.91, SD (0.49) l.min⁻¹, respectively. Therefore, both authors concluded that transpulmonary thermodilution cardiac output measurement via the brachial artery catheter is interchangeable with the cardiac output derived from a pulmonary artery catheter. In addition, Wouters et al. [12] showed pulse contour analyses using a brachial arterial catheter to agree with pulmonary artery thermodilution, bias 1.08, SD (0.75) l.min⁻¹.

The main purpose of our study was to show the possibility to continue cardiac output monitoring, by pulse contour, in case of problems with the femoral arterial line and was not set up to prevent the placement of the femoral arterial line at start. To our opinion, the high agreement between CO_{fem} and CO_{rad}, bias -0.007, SD (0.31) l.min⁻¹, allows us to change from femoral to radial artery pressure line for continuation of the cardiac output monitoring. Furthermore, the high agreement between CO_{fem} and CO_{rad} indicate a sufficient pressure waveform quality of the radial artery pressure for pulse contour analysis. This although, different authors [13-15] reported that the systolic radial artery pressure is higher compared to systolic aortic pressure, diastolic and mean pressures were found to be equal between both sites.

The software in the PiCCO systems used is based on an extension of the original Wesseling algorithm [3]. In this algorithm stroke volume is related to the area under the systolic portion of the pressure wave with corrections made on basis of individual aortic compliance and systemic vascular resistance of the patient. As accounts for all pulse contour methods, ideally the aortic pressure waveform should be used as input of the pulse contour method. Certainly, the femoral artery pressure waveforms as well as the brachial artery waveform come closer to this aortic pressure waveform than the radial artery waveform. But, by integration the pressure over the whole systolic period, to obtain stroke volume, the pressure waveform purity becomes less relevant. Also, Wesseling et al. [3] observed no difference between pulse contour cardiac output derived from the aortic pressure and that from the radial artery pressure. Therefore, a dominant role of arterial pressure waveform on the computation of cardiac output by pulse contour seems not present. Our results confirmed this.

Conclusion

We conclude that the femoral artery pressure and radial artery pressure are interchangeable as input of the PiCCO device to compute cardiac output allowing to change to the radial artery pressure line if the preferred femoral artery pressure line is no longer available for use. Regular visual inspection of the pressure waveform on the monitor screen is strongly advised.

References

1. Pinsky MR. Functional hemodynamic monitoring. *Intensive Care Medicine* 2002; **28**:386-8.
2. Jansen JR, Wesseling KH, Settels JJ, Schreuder JJ. Continuous cardiac output monitoring by pulse contour during cardiac surgery. *European Heart Journal* 1990; **11 Suppl I**:26-32.
3. Wesseling KH, Jansen JR, Settels JJ, Schreuder JJ. Computation of aortic flow from pressure in humans using a nonlinear, three-element model. *Journal of Applied Physiology* 1993; **74**:2566-73.
4. Godje O, Hoke K, Lamm P, Schmitz C, Thiel C, Weinert M, Reichart B. Continuous, less invasive, hemodynamic monitoring in intensive care after cardiac surgery. *Thoracic and Cardiovascular Surgery* 1998; **46**:242-9.
5. Godje O, Hoke K, Lichtwarck-Aschoff M, Faltchauser A, Lamm P, Reichart B. Continuous cardiac output by femoral arterial thermodilution calibrated pulse contour analysis: comparison with pulmonary arterial thermodilution. *Critical Care Medicine*. 1999; **27**:2407-12.
6. Godje O, Friedl R, Hannekum A. Accuracy of beat-to-beat cardiac output monitoring by pulse contour analysis in hemodynamical unstable patients. *Medical Science.Monitor*. 2001; **7**:1344-50.
7. Linton NW, Linton RA. Estimation of changes in cardiac output from the arterial blood pressure waveform in the upper limb. *British Journal of Anaesthesia* 2001; **86**:486-96.
8. Jansen JR, van den Berg PC. Cardiac Output by Thermodilution and Arterial Pulse Contour Techniques. In: Functional Hemodynamic Monitoring. Pinsky MR, Payen D. (Eds) Berlin Heidelberg New York: Springer-Verlag, 2005:135-152.
9. Della Rocca G, Costa MG, Coccia C, Pompei L, Di Marco P, Vilardi V, Pietropaoli P. Cardiac output monitoring: aortic transpulmonary thermodilution and pulse contour analysis agree with standard thermodilution methods in patients undergoing lung transplantation. *Canadian Journal of Anaesthesia* 2003; **50**:707-11.
10. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; **1**:307-10.
11. L'E Orme RM, Pigott DW, Mihm FG. Measurement of cardiac output by transpulmonary arterial thermodilution using a long radial artery catheter. A comparison with intermittent pulmonary artery thermodilution. *Anaesthesia* 2004; **59**:590-4.

12. Wouters PF, Quaghebeur B, Sergeant P, Van Hemelrijck J, Vandermeersch E. Cardiac output monitoring using a brachial arterial catheter during off-pump coronary artery bypass grafting. *Journal of Cardiothoracic and Vascular Anesthesia*. 2005; **19**:160-4.
13. Kanazawa M, Fukuyama H, Kinefuchi Y, Takiguchi M, Suzuki T. Relationship between aortic-to-radial arterial pressure gradient after cardiopulmonary bypass and changes in arterial elasticity. *Anesthesiology* 2003; **99**:48-53.
14. Soderstrom S, Nyberg G, O'Rourke MF, Sellgren J, Ponten J. Can a clinically useful aortic pressure wave be derived from a radial pressure wave? *British Journal of Anaesthesia*. 2002; **88**:481-8.
15. Pauca AL, Hudspeth AS, Wallenhaupt SL, Tucker WY, Kon ND, Mills SA, Cordell AR. Radial artery-to-aorta pressure difference after discontinuation of cardiopulmonary bypass. *Anesthesiology* 1989; **70**:935-41.

Letter to the editor

Monitoring cardiac output from the radial artery pressure waveform

R.M. L'E. Orme and D.W. Pigott

R.M. L'E. Orme, Cheltenham General Hospital Cheltenham GL53 7AN, UK

D.W. Pigott, John Radcliffe Hospital Oxford OX3 9DU, UK

We would like to raise a number of points concerning de Wilde and colleagues' paper [1] comparing the radial and femoral artery for measurement of cardiac output using the PiCCO system (Pulsion Medical Systems, Munich, Germany). Their study involved collecting radial and femoral artery pressures traces onto computer and then playing back the data through the PiCCO device. The radial artery pressure was recorded from a 3.5-cm catheter, whereas a 4 F 16cm PiCCO catheter was used for the femoral artery waveform. The calibration factor obtained from the femoral catheter by arterial thermodilution was then used to calculate cardiac output from the radial artery waveform. Bland-Altman analysis of radial vs femoral artery-derived cardiac output yielded acceptable bias and a precision of -0.01 l.min^{-1} and 0.61 l.min^{-1} , respectively.

We believe that their conclusion that radial and femoral artery pressure waveforms are interchangeable for cardiac output determination using the PiCCO system fails to appreciate the fundamental issue of calibration. To determine cardiac output via pulse contour analysis, it is first measured by transpulmonary arterial thermodilution using a modified Stewart-Hamilton equation to obtain a value for aortic impedance. Previously, we have shown that to achieve successful calibration requires the thermistor-tipped arterial catheter to be sited centrally [2]. We compared thermodilution measurements of cardiac output from a 50 cm radial artery catheter using the PiCCO system with a pulmonary artery catheter. Although the catheter tip was likely to lie within either the distal subclavian or proximal brachial artery, we did not use the brachial route as stated by de Wilde and colleagues. In addition, we were unable to measure cardiac output and hence reliably calibrate the device for pulse contour analysis when the radial catheter was withdrawn by more than 5cm despite using iced injectate to improve the signal to noise ratio. Pulsion Medical Systems also recommend that the device is calibrated at least once every 24hrs to maintain acceptable accuracy.

We believe, therefore, that the authors' study has limited practical application as it is impossible accurately to measure cardiac output by pulse contour analysis using the PiCCO system via a short radial catheter without first inserting a centrally sited thermistor-tipped catheter. Only in the unlikely situation of the failure of the dedicated arterial catheter following successful calibration could a radial catheter be used; and then it could only be used for the short-term.

References

1. de Wilde RBP, Breukers RBGE, van den Berg PCM, Jansen JRC. Monitoring cardiac output using the femoral and radial arterial pressure waveform. *Anaesthesia* 2006; **61**:743–6.
2. L'E Orme RM, Pigott DW, Mihm FG. Measurement of cardiac output by transpulmonary arterial thermodilution using a long radial catheter. A comparison with intermittent pulmonary artery thermodilution. *Anaesthesia* 2004; **59**:590–4.

A reply

We thank Drs Orme and Pigott for their comments. They questioned our conclusion that radial and femoral artery pressure waveforms are interchangeable because it fails to take into account the fundamental issue of calibration. This is only partially correct. Calibration by transpulmonary thermodilution with detection of the dilution curve in the radial artery leads to an overestimation of cardiac output [1]. This overestimation is not related to a poor signal-to noise ratio, which might otherwise be compensated for by using iced injectate.

It is related to loss of indicator during its transport from injection to detection site.

In their letter, Orme and Pigott conclude that after changing from the femoral to the radial pressure site, the pulse contour method could be used for a maximum of 24hrs because Pulsion Medical Systems recommend calibrating the PiCCO device at least once every 24hrs. In our opinion, they have concentrated too much on the use of monitoring absolute cardiac output over longer time periods and therefore the weakness in the pulse contour method. They have ignored the ability of this technique in monitoring changes in cardiac output due to interventions or treatments over short time periods (such as hours) as well as its ability to monitor changes in the patient's filling status by determining stroke volume variation or pulse pressure variation.

A further reason to undertake our study was our curiosity about whether the shape of the pressure wave form influences the results of pulse contour analyses. The pulse contour method used by Pulsion can be subdivided into two parts. The first part is related to the integration of the area under the systolic part of the pressure curve. This process filters out the shape of the curve. The second part is related to the shape of the pressure wave by multiplication of the arterial compliance with the first derivative of the arterial pressure. These two parts must be added to compute cardiac output. Although the shapes of the femoral and radial artery differ, the calculated cardiac output does not.

We showed that the more frequently available radial artery pressure is interchangeable with the femoral artery pressure. Both sites can be used to determine cardiac output estimates of equal quality. We hope this finding will result in more widespread use of this device and further work on its calibration by methods other than transpulmonary femoral thermodilution.

R.B.P. de Wilde, P.C.M. van den Berg, J.R.C. Jansen
Leiden University Medical Centre, NL-2300 RC, Leiden, the Netherlands
E-mail: r.b.p.de_wilde@lumc.nl

Reference

1. L'E Orme RM, Pigott DW, Mihm FG. Measurement of cardiac output by transpulmonary arterial thermodilution using a long radial catheter. A comparison with intermittent pulmonary artery thermodilution. *Anaesthesia* 2004; **59**:590–4.